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Mechanical Performance of Biodegradable Natural Composites Reinforced with Calotropis Gigantea Fibers

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Abstract: *Biodegradable composites reinforced with plant-based fibers are emerging as promising candidates for lightweight and sustainable material solutions. Among these, Calotropis gigantea an underutilized plant-based fiber holds potential as a sustainable reinforcement material. This study investigates the mechanical characterization of Calotropis gigantea stem fibers, using corn flour as an eco-friendly matrix to develop biodegradable composites. Fibers were extracted via the retting process and incorporated into corn flour in varying weight ratios. Composite laminates with different fiber-to-resin proportions were fabricated to check the stability for the novel fiber composite, among which 44.4% w/w fiber content was found optimal for mechanical testing due to superior laminate stability. A series of five replicates were tested to ensure accuracy and repeatability. The results revealed a tensile strength of 31.34 MPa, flexural strength of 97.20 MPa, and a notably high impact strength of 28.5 kJ/m², indicating the material's potential for impact-sensitive applications. Although marginal gains were seen in tensile and flexural performance, the composite demonstrated significant enhancement in impact resistance, highlighting its practical viability in lightweight structural, packaging, and insulation components where energy absorption is critical.*

Keywords: Natural Fibers, Calotropis Gigantea, bio-composite, Corn flour, Mechanical Testing*This is an open access article under the creative commons license https://creativecommons.org/licenses/by-nc-nd/4.0/*
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Introduction

Natural fibers sourced from plants, animals, and minerals have gained significant attention in sustainable material development due to their renewable origin, biodegradability, and environmental compatibility. Plant-based fibers like jute, hemp, sisal, and *Calotropis gigantea* are primarily composed of cellulose and exhibit a porous internal structure, contributing to desirable traits such as low weight, moderate mechanical performance, and effective thermal and acoustic insulation. These fibers show anisotropic behavior, meaning

their properties vary with direction, which is crucial in composite applications. The efficiency of natural fiber-reinforced composites largely depends on the fiber content, orientation, and the strength of bonding at the fiber–matrix interface. A strong interface improves stress transfer and structural stability, whereas weak adhesion may cause issues like delamination or fiber pull-out. Models like the rule of mixtures are often applied to predict composite behavior based on constituent properties and ratios. Given their lightweight, insulating capabilities, and environmental benefits, such natural fiber composites are promising alternatives in applications demanding sustainability and functional performance. In addition to its ornamental value, Calotropis gigantea has been recognized for its medicinal properties in traditional literature. Recent studies on Calotropis gigantea fiber (CGF) and other natural fibers underscore a significant shift toward sustainable, bio-based composites. The body of literature presents a holistic view of CGF's growing potential in replacing conventional synthetic reinforcements. However, the diversity of fabrication techniques, fiber treatments, hybridization, and testing conditions presents both opportunities and challenges in establishing unified performance benchmarks.

Highlighting Mechanical Performance, CGF vs Other Natural Fibers. Gopal et al.[1] highlight CGF composites fabricated via compression molding, achieving impressive mechanical values up to 142.46 MPa flexural and 93.13 MPa tensile strength. These exceed the performance metrics reported for jowar, banana, or pineapple leaf fiber-based composites, such as those by Prasad et al.[2], Herlinasari et al.[3], and Ansari et al.[4] In contrast, Chinnasamy et al.[5] and Yamini et al.[6] found hybrid or treated jute/sisal/kenaf fibers yielded better damping and vibration properties. While CGF shows excellent static mechanical behavior, its dynamic performance and damping characteristics remain underexplored, presenting a potential area for further investigation. Zaman et al.[7] and Kalpana et al.[8] confirmed about Effect of Chemical Treatment and Hybridization that alkaline and benzoyl treatments enhance interfacial adhesion and increase mechanical strength by improving fiber-matrix bonding. About Hybridization, as in Ganeshan et al.[9] and showed promise combining CGF with other fibers (e.g., Prosopis Juli flora or jute) resulted in balanced property profiles, especially when optimized with methods like Taguchi-grey analysis. Prominence Environmental Impact and LCA have been discussed by Rashid et al.[10] and Jeyapragash et al.[11], explored life cycle assessment (LCA) and environmental benchmarking. With Rashid's findings indicating a 30–50% reduction in carbon footprint, it emphasizes the environmental edge of bio-based composites. Yet, CGF-specific LCA data remains sparse, limiting broader eco-certification and industrial adoption. The Tribological and Moisture Behaviour studied by Suresh et al.[12] and Ashok et al.[13] examined wear and tribological behaviour of CGF composites, with enhancements seen via lignite fly ash and optimized loads. However, limitations such as increased water absorption, as seen in Pradiza et al.[14] work with other natural fibers, suggest CGF's moisture resistance still requires improvement through surface treatments or hydrophobic coatings. Mallick[15] offers a comprehensive update on composite materials, including new content on nanocomposites, natural fibers, fiber architecture, and cost analysis. It features expanded coverage of test methods, manufacturing techniques, and real-world applications, reinforcing both theoretical understanding and practical problem-solving skills. Vinod et al.[16] developed jute fiber-reinforced epoxy composites with 0%, 5%, and 10% Calotropis gigantea stem powder filler. The 10% filler composite showed enhanced mechanical and thermal properties due to improved filler content and distribution. SEM analysis confirmed better interface bonding and reduced voids, supporting its superior performance. So, by understanding how these fibers interact with the materials around them, scientists can make composites that work better for things like construction or packaging.

Sinha et al.[17] discusses the mechanical properties of natural fiber composites (NFCs) reinforced with fibers like jute, abaca, coconut, kenaf, sisal, and bamboo. It highlights key factors affecting performance, such as matrix and fiber type, interfacial adhesion, and compatibility, and points out a research gap in vibration studies involving fillers like red mud and fly ash. Oboh et al.[18] developed natural rubber composites reinforced with coir fiber cellulosic nanoparticles (CFNP) derived from coconut husk. CFNP (68–311 nm) enhanced tensile strength by 112% and improved tensile modulus. Slightly higher water absorption and a minor reduction in thermal stability were observed, confirming CFNP's potential as sustainable industrial rubber reinforcement. Munisamy et al.[19] explored the fabrication of polymer matrix composites reinforced with natural fibers like coir, banana, and sisal for potential use in automotive seat shells. Various tests flexural, hardness, impact, water absorption, and density were conducted to evaluate mechanical and physical properties. Results confirmed that these abundant, renewable fibers enhance performance, offering a sustainable alternative to synthetic composites. Ganesh et al.[20] explained the use of natural fiber-reinforced polymer composites as sustainable alternatives to glass and carbon fibers in wind turbine components like blades and nacelles. It addresses material requirements, properties, manufacturing methods, and common defects. The study highlights the environmental and economic benefits of natural fibers and explores future directions for their application in wind energy systems. Ganeshan et al.[21] optimized parameters affecting organic fiber-based hybrid composites using *Calotropis gigantea* and *Prosopis juliflora* fibers. Taguchi-grey analysis identified 20 wt.% of each fiber, 6% NaOH treatment, 100 °C, and 14 MPa as ideal conditions. *Calotropis gigantea* was most influential in enhancing mechanical properties, guiding future composite material development. Ashori et al. [22] explores the potential of *Calotropis gigantea* (mudar) bark and seed fibers as alternatives in fiber-reinforced composites.

Chemical analysis shows high holocellulose and cellulose content. Bark fibers, with favorable mechanical properties (381 MPa tensile strength, 9.7 GPa modulus), resemble softwood fibers, indicating strong potential as sustainable reinforcement materials. Salman et al.[23] investigated *Calotropis procera* latex extract (CPLE) as a green corrosion inhibitor for mild steel in 1M HCl. At 200 ppm, CPLE showed up to 94.26% efficiency. It acts as a mixed-type inhibitor via adsorption, following Langmuir isotherm. Surface and computational analyses confirmed strong interaction, especially by 3,7,10-trimethyl pentadecane-ol. Sreenivasan et al.[24] reported that Calotropis gigantea fibers exhibit lower stiffness than flax or jute but possess good energy absorption, making them promising for impact-related uses. Building on this, the present study introduces a novel CGF/cornflour-based biodegradable composite an unexplored system while extending performance evaluation beyond conventional tensile or thermal analyses. By incorporating interlaminar shear strength, thermal conductivity, and biodegradability assessments, this work offers a comprehensive insight into CGF composites' potential for sustainable, moderate-load, and insulation-focused applications.

Using Calotropis gigantea fibers in combination with a cornflour-based resin, both being naturally abundant and renewable, presents a viable alternative to synthetic fiber reinforced composites. This substitution promotes environmental sustainability, as synthetic fibers are known to be non-biodegradable and potentially hazardous, contributing to long-term ecological pollution. A collective body of research presented within these studies underscores the immense promise of natural fibers as invaluable reinforcement materials in composite manufacturing. However, a very scarce amount of work has been done with Calotropis Gigantea fiber with a bio-based resin such as cornflour. The present work aims to derive the mechanical properties of bio composite which is abundantly available and less hazardous to

the environment. While extensive research has been conducted on natural fibers combined with synthetic resins or hybridized with synthetic fibers, no prior study has reported the use of Calotropis gigantea stem fibers in combination with a natural resin such as cornflour to develop a fully bio-based composite. This gap highlights the novelty of the present work, which explores the fabrication and characterization of a completely natural composite system using Calotropis gigantea and cornflour offering an eco-friendly alternative with potential applications in sustainable materials engineering. Only a limited amount of research has been conducted in the area of natural fibers, particularly with Calotropis gigantea (CGF), highlighting a significant gap in the current literature.

2. Materials and Methods

In this study, lignocellulosic fibers were extracted from the stem bark of *Calotropis gigantea* (CG) through a controlled water retting process. The stems were immersed in water for 48 hours to facilitate microbial degradation of the pectins and other binding substances, enabling manual separation of the fibers. Post-extraction, the fibers were thoroughly rinsed with clean running water to remove residual impurities and then air-dried under ambient conditions to preserve their natural morphology. A cornflour-based aqueous slurry was employed as the bio-resin matrix, serving as a natural polymeric binder for composite fabrication.

2.2 Extraction of Calotropis Gigantea fibers

CG plant stems were harvested from waste lands in dry condition near Edulabad and Warangal Highway, India. As latex is characteristically present in the stem of CG plant, they discharged out when the stems were cut for fiber extraction. After the removal of leaves and petioles from the stem, they were soaked in water for a period of two nights by putting them in a large tub. Beyond two days of time, the latex stops oozing out from the petioles and hence the fibers start to expose itself from the bark. Then the fibers were extracted through retting process and the extracted fibers were dried at room temperature for two days. After drying, any extraneous matter that may still be adhering to them was removed. The extracted fibers were then used for composite making. The Calotropis gigantea fiber is shown in Figure 1.

Fig. 1. Visual illustration of Calotropis gigantea, showcasing the plant and its extracted fibers.

2.3 Fabrication of Composites

Composite laminates were fabricated using the conventional hand lay-up method. A flowable corn flour–water slurry, acting as a natural thermoplastic binder, was uniformly applied to a flat mold. Pre-weighed and dried Calotropis gigantea (CG) fibers were layered over the matrix, with alternating layers of fiber and matrix applied to ensure uniform dispersion and minimize voids. The lay-up was microwave-treated for 60 minutes to partially gelatinize the matrix and anchor the fibers, followed by post-curing at 60 °C for 1 hour to enhance mechanical strength and dimensional stability. Through multiple trials, the optimal formulation was identified as 2.0 g fiber and 2.2 g corn flour (44.4% w/w), providing superior laminate integrity. Lower ratios yielded weak, unstable composites.

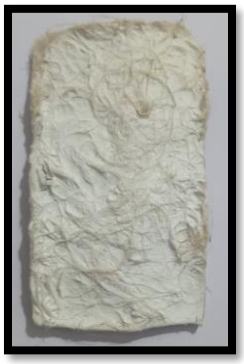

Fig. 2 Stable specimen obtained with 44.4% w/w fiber-resin ratio

The combination of Calotropis gigantea fiber's inherent tensile characteristics with the bonding ability of corn flour produced a biodegradable composite with enhanced flexibility and durability. After curing, the laminates were conditioned at room temperature for 24 hours before machining. Specimens were cured in moulds in accordance with standard ASTM procedures:

- ASTM D638 for tensile testing,
- ASTM D790 for flexural strength, and
- ASTM D256 for impact resistance.

Each test was conducted on five replicate samples to ensure consistency and reliability in results. Five Samples each with 2 g of fiber and 2.2 g of cornflour slurry and five samples each with 2.2 g of fiber and 2.4 g of cornflour slurry was made.

3. Experimental details

3.1 Tensile Testing

Tensile characterization of the bio-composite specimens was carried out in accordance with ASTM D638M-10 standards, with dimensions standardized at 165 mm × 13 mm × 3.2 mm. Two sets of laminates were prepared, each comprising five specimens reinforced with Calotropis gigantea fibers at loadings of 2.0 g and 2.2 g, respectively. The tests were performed using a Universal Testing Machine (UTM) at a crosshead speed of 5 mm/min and a gauge length of 100 mm. The average ultimate tensile strength obtained was 31.34 MPa for the 2.0 g fiber-reinforced specimens and 20.39 MPa for those with 2.2 g fiber content. Consistency across the five replicates validated the repeatability and statistical significance of the measurements.

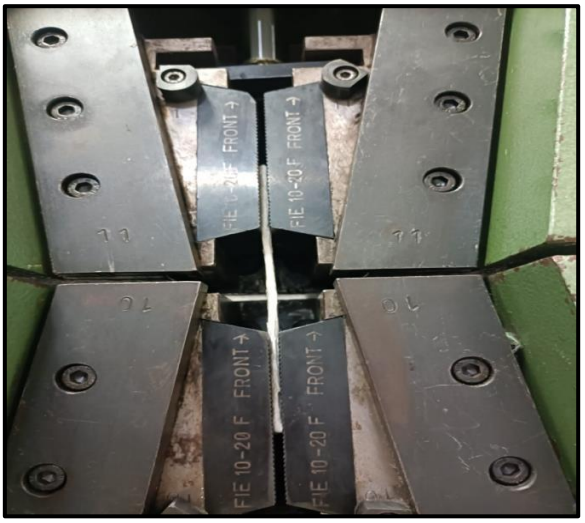

Fig 2. Visualization of the specimen loaded for tensile test

3.2 Flexural Testing

The flexural properties of the Calotropis gigantea (CG) fiber-reinforced composites were evaluated in accordance with ASTM D790-10 standards. Rectangular specimens were fabricated with dimensions of 125 mm in length, 12.7 mm in width, and 3.2 mm in thickness. Two sets of composite samples—each comprising five specimens—were tested, containing fiber loadings of 2.0 g and 2.2 g, respectively. Flexural testing was performed using a three-point bending setup. The average flexural strength recorded was 97.20 MPa for the 2.0 g fiber-reinforced composites and 70.64 MPa for those containing 2.2 g of fiber. These results highlight the superior flexural performance of the 2.0 g fiber formulation.

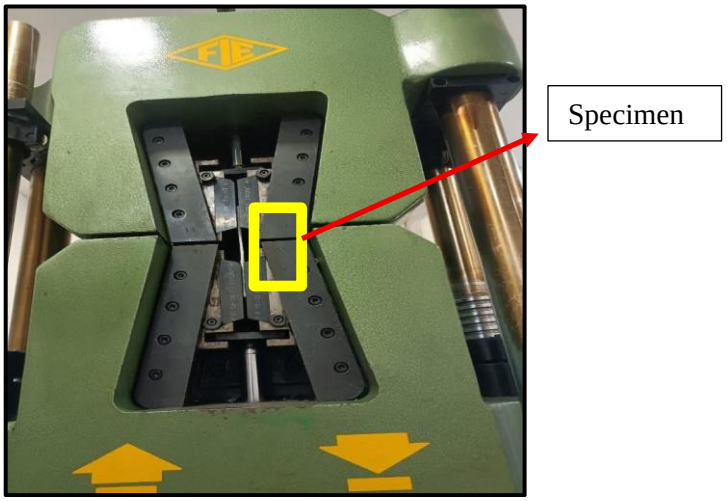

Fig 3. Visualization of the specimen loaded for Flexural test

3.3 Impact Testing

The impact resistance of Calotropis gigantea (CG) fiber-reinforced composites was assessed following ASTM D256-10 standards using an Izod impact testing setup. Specimens with standard dimensions were fabricated for two compositions: one with 2.0 g fiber content and

the other with 2.2 g fiber content. A total of five replicates were tested for each composition to ensure data consistency and statistical reliability. The average impact strength observed was 28.5 kJ/m² for the 2.0 g fiber specimens and 19.3 kJ/m² for the 2.2 g fiber specimens. The higher energy absorption capacity exhibited by the 2.0 g fiber composite suggests improved toughness and fiber–matrix interfacial bonding at this ratio.

Fig 4. Visualization of the specimen loaded for Impact test

4. Result and Discussion

The tensile strength of the Calotropis Gigantea Fiber Reinforced Plastic composites depends upon the withstanding of the load transferred by the surviving fibers from the broken fibers. The tensile strength for the CG fiber composite is observed that the CG fiber in specimen carrying 2 g of fiber content resulted in a mean tensile strength of 31.34 MPa. With increase in fiber content in specimen carrying 2.2 g the tensile strength is observed to be 20.39MPa. The tensile strength of the CGF composites depends upon the load to be transferred to the surviving fibers from the broken fibers. Figure 2 depicts the tensile set up to know the tensile properties of CGF composites with the content of fiber, as the corn flour resin flows into the hollow portions of the CG fibers at the time of composites fabrication and renders better interfacial interlock between matrix and fibers, such process could be noticed. As expected, the tensile strength and modulus of CGF composites are comparable with other plant fiber composites.

Ramesh et al.[1] and Gopal et al.[2] highlight CGF composites fabricated via compression molding, achieving impressive mechanical values up to 142.46 MPa flexural and 93.13

MPa tensile strength. Ashori et al. [23] explores the potential of CGF bark and seed fibers as alternatives in fiber-reinforced composites giving bark fibers, with favorable mechanical properties 381 MPa tensile strength, 9.7 GPa modulus whereas when fabricated using cornflour the flexural strength for the CG fiber composite is observed that the Calotropis gigantea fiber in specimen carrying 2 g of fiber gave a mean flexural strength of 97.20 MPa whereas specimen carrying 2.2 g of fiber gave flexural strength of 70.64 MPa as shown in Figure 3. The impact strength for the CGF composite is observed that the fiber in specimen carrying 2.2 g of fiber gave a maximum impact strength of 34.6 kJ/mm^2 than specimen carrying 2 g of fiber which gave an impact strength of 21.5 kJ/mm^2 respectively shown in Figure 4. The Variation of Tensile, Flexural and Impact strength (kJ/mm^2) of fiber with varying fiber content can be observed in Figure 5 which concludes that CG fiber can be used in various application where better impact strength is required. The mechanical behavior of Calotropis gigantea fiber (CGF) composites reveals a distinct trend—limited improvement in tensile and flexural strength, but a notable enhancement in impact strength. This can be attributed to the fiber's unique microstructural and compositional characteristics. CGF has a high lignin content, which contributes to its toughness and energy-dissipating ability, making it particularly effective under dynamic loading conditions such as impact. Its porous and elastic structure further enhances this behavior by enabling better absorption and redistribution of impact energy. Additionally, CGF is inherently flexible and ductile, allowing it to deform without breaking, which is critical for resisting sudden forces. However, under static loads like tension or bending, the performance is constrained due to weak interfacial bonding between the CGF and cornflour matrix. The natural incompatibility between the hydrophilic fiber and the relatively soft matrix results in inefficient stress transfer, leading to early fiber pull-out or matrix cracking. Moreover, CGF's irregular microstructure and lower cellulose content limit its ability to bear high tensile or flexural loads. The cornflour matrix, being biodegradable and eco-friendly, lacks the stiffness and bonding strength of synthetic resins, which further restricts the composite's load-bearing capabilities. Thus, while CGF composites excel in impact performance due to their energy-absorbing nature, their tensile and flexural strengths remain modest, governed by limitations in fiber-matrix interaction and structural stiffness. Despite the common assumption that adding fibers enhances composite strength, this study found that increasing the weight fraction of *Calotropis gigantea* fibers did not proportionally improve tensile or flexural properties. Several factors contribute to this behavior: poor fiber–matrix interfacial bonding due to hydrophilicity, fiber agglomeration leading to inhomogeneous stress distribution, and reduced matrix continuity that compromises structural integrity. Additionally, the porous surface of CGF increases void formation at higher loadings, while inadequate interfacial shear strength promotes fiber pull-out instead of rupture. These issues, combined with uneven stress distribution (stress shielding), result in premature failure and diminished mechanical performance at higher fiber contents. The declining tensile and flexural strength with increasing CGF content is primarily due to interfacial inefficiencies, processing defects, and microstructural imbalance. Addressing these issues may require surface treatments (e.g., alkali, silane) or matrix modifications (e.g., plasticizers, coupling agents) to enhance compatibility and performance.

The results of this study demonstrate that Calotropis gigantea fiber–reinforced cornflour composites possess moderate mechanical strength, good thermal insulation, and biodegradability, making them promising candidates for non-structural and semi-structural applications. While tensile and flexural strengths do not improve significantly with higher

fiber loading, the composites exhibit adequate performance for packaging, thermal insulation panels, acoustic boards, and low-load automotive interior components. The use of a completely natural fiber–matrix system underscores the material's relevance in the biodegradable materials sector, particularly where environmental sustainability is a key concern. These findings pave the way for cost-effective, eco-friendly composite solutions in industries transitioning away from petroleum-based materials.

The experimental results were statistically analyzed to determine the central tendency and variability using the mean, standard deviation (SD), and standard error of the mean (SE). These parameters were calculated using the following standard formulas:

Mean ($\bar{x}$):

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation (SD):

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

The SE indicates the precision of the sample mean as an estimate of the population mean. These statistical calculations were carried out to ensure the reliability and reproducibility of the measured values. Table 1 shows the Tensile, flexural and Impact strength for five samples each carrying 2 g and 2.2 g of fiber, with standard deviation and standard error.

Table 1: Tensile, flexural and Impact strength for five samples carrying 2 g and 2.2 g of fiber, with standard deviation and standard error.

Sample	**Tensile Strength (MPa)**		**Flexural Strength (MPa)**		**Impact Strength (kJ/m²)**	
	2 g	**2.2 g**	**2 g**	**2.2 g**	**2 g**	**2.2 g**
S1	30.5	20.39	95.2	70.62	27.8	34.6
S2	31.8	21.39	97.8	72.62	28.6	35.6
S3	32.1	20.39	98.3	72.69	29	35.89
S4	30.9	20.39	96.7	71.42	28.3	35.65
S5	31.5	21.39	98	72.62	28.7	35.6
Mean	31.36	20.79	97.2	71.994	28.48	35.468
Standard Deviation	0.65	20.39	1.27	0.933	0.45	0.499

Table 2: Error Analysis Values

S. No.	Testing Machine	Test Name	% Error	Error Value
1	Universal Testing Machine	Tensile	±0.5%	±0.157 MPa (0.5% of 31.36 MPa)
2	Universal Testing Machine	Flexural	±0.5%	±0.486 MPa (0.5% of 97.20 MPa)
3	Impact Testing Machine	Impact	±1.0%	±0.2 kJ/m² (1.0% of 28.48 kJ/m²)

Similar tests of repeatability were carried out for 2.2 g of fiber mixed with 2.4 g of cornflour slurry and the average of the results was considered. Fig 6 shows the comparison for Tensile, Flexural and Impact strength of specimens carrying 2 g of fiber and 2.2 g of fiber content.

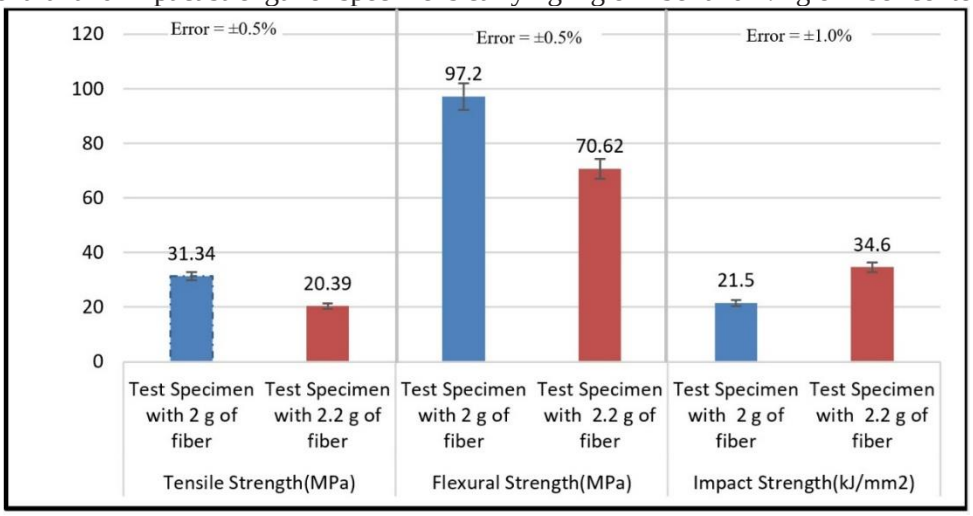

Fig 6 Comparison for Tensile, Flexural and Impact strength of specimens carrying 2 g of fiber and 2.2 g of fiber content.

5. Conclusion

In this study, a novel biodegradable composite material was developed using *Calotropis gigantea* (CG) stem fibers as reinforcement and corn flour as a bio-based matrix. The composites were fabricated using a conventional hand lay-up process, and various mechanical properties were evaluated. The following conclusions can be drawn:

- The incorporation of CG fibers improved the composite's mechanical behavior, particularly its impact resistance, which reached 34.6 kJ/m² at an optimal fiber content of 44.4% w/w.
- While tensile and flexural strengths showed only moderate gains, the mechanical performance was sufficient for non-load-bearing applications.
- The limited enhancement in tensile and flexural properties at higher fiber contents was likely due to poor fibre–matrix adhesion and fiber agglomeration, indicating a need for surface treatment or compatibilizers.
- The composites demonstrated low thermal conductivity and biodegradability, making them promising for eco-friendly applications in packaging, insulation, and automotive interiors.

- The optimal formulation (2.0 g CG fibre to 2.2 g matrix) ensured laminate stability and consistent mechanical performance across test specimens.

Future work should focus on interface engineering, processing optimization, and long-term durability studies to expand the structural utility of CGF-based bio composites across wider engineering applications.

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